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Co-Principal Investigators: Wallace S. Broecker
Inez Fung

Columbia University

TASK A: CLIMATE AND ATMOSPHERIC MODELING STUDIES

Climate Model Development and Applications

The research conducted during the past year in the climate and atmospheric modeling programs has been focused on the development of appropriate atmospheric and upper ocean models, and preliminary applications of these models. Principal models are a one-dimensional radiative-convective model, a three-dimensional global climate model, and an upper ocean model. Principal applications have been the study of the impact of CO_2, aerosols and the solar 'constant' on climate.

Progress has been made in the 3-D model development towards physically realistic treatment of these processes. In particular, a map of soil classifications on 1° x 1° resolution has now been digitized, and soil properties have been assigned to each soil type. Using this information about soil properties, a method has been developed to simulate the hydraulic behavior of soils of the world. This improved treatment of soil hydrology, together with the seasonally varying vegetation cover, will provide a more realistic study of the role of the terrestrial biota in climate change.

A new version of the climate model has been created which follows the isotopes of water and sources of water (or colored water) throughout the planet. Each isotope or colored water source is a fraction of the climate model's water. It participates in condensation and surface evaporation at different fractionation rates and is transported by the dynamics. A major benefit of this project has been to improve the programming techniques and physical simulation of the water vapor budget of the climate model. Applications include simulations of deuterium and oxygen-18 for both current climate 18,000 years ago, the

source of precipitation in each grid box in the North Hemisphere, and a stratospheric tritium experiment to simulate the atomic testing of the 1950's and 60's (Koster et al., 1986).

A mixed layer-diffusive thermocline ocean model has been incorporated into the 3-D climate model to allow the study of the effect of ocean thermal inertia on the timing of the greenhouse warming due to slowly increasing levels of CO_2 and other trace gases in the atmosphere. In this model, the geographically dependent thermocline diffusion coefficients are obtained from an empirical relationship that relates the stability at the base of the mixed layer and the diffusion rate of bomb-produced tritium observed in the GEOSECS program. It is found that with a climate sensitivity of approximately 4°C for doubled CO_2, the response time of surface temperature is of order 100 years because of the thermal inertia of the ocean (Hansen et al., 1984).

A 1-D mixed layer-diffusive ocean model, derived from the 3-D representation used in the climate model, has been used to study climate response times (Hansen et al., 1985). The results show that climate response times are particularly senstitive to (1) the amount that the climtae response is amplified by feedbacks and (2) the representation of ocean mixing. The results also show that most of the warming due to trace gases which man has added to the atmosphere probably has not appeared yet.

The 3-D climate model with the diffusive ocean has been used to study the transient climate response to slow changes in atmospheric composition due to volcanic eruptions and increasing concentrations of CO_2 and other trace gases. The results thus far demonstrate that there is a natural variability in the model and that global warming in the model begins to rise above the level of natural variability by about 1990.

Investigation of the sources and sinks of atmospheric CO_2 has focused on the seasonal exchange between the atmosphere and the terrestrial biosphere. Approximately linear relationships have been found between atmospheric CO_2 concentrations and a vegetation index derived from satellite data (Tucker et al., 1986). Improved representation of the photosynthetic uptake and soil release of carbon have been obtained using these satellite data together with auxiliary ground data, and have been used as input functions to the 3-D tracer transport model developed at GISS. The simulated distributions of atmospheric CO_2 show reasonable agreement with those observed, demonstrating for the first time the feasibility of using global, multi-temporal satellite data for the study of the global carbon cycle (Fung et al., 1986).

SAGE II

In accordance with our task to carry out modeling and interpretation of SAGE II data, we have developed a 23-level version of the 3-D GCM to be used. This model extends from the surface up to 0.01 mb (~85 km) (Rind et al., 1984). Model improvements during the past year include the incorporation of gravity wave-induced stratospheric drag. In preparation for estimating the impact of SAGE II observed stratospheric aerosols on climate, preliminary experiments have been run with a data set for El Chichón collected by Pollack (AMES) and McCormick (Langley). The preliminary SAGE II data has been analyzed and plotting routines developed to portray it. An analysis of the SAGE retrieval of water vapor in the tropical lower stratosphere has also been prepared.

TASK B

CLOUD CLIMATOLOGY

Over the past year we have continued to evaluate the performance of the ISCCP cloud detection algorithm, concentrating initially on its application to geosynchronous data, with an eventual switch of the developed methodologies to data from polar orbiting satellites. In the process, a number of improvements were made, in particular:

a) an improved technique for tracking small scale (~5° K and less) day to day variability in clear-sky continental temperatures.

b) a number of techniques for the statistical assessment of cloud detection uncertainties due to certain cloud types which are spatially and temporally invariant.

c) a method used to detect those cloudy regions which have long-term (on the scale of weeks to months) spatial and temporal stability. The latter method is particularly useful in estimating cloudiness over the algorithmically most difficult scenes, i.e., continental areas with persistent low-level cloudiness.

We developed a generalized version of the detailed radiative transfer model, which can simulate the observations of different satellite radiometers, provided the filter function is known. The detailed radiative transfer model has been used to simulate NOAA, GOES, and METEOSAT VIS, IR and water vapor channels. The model has been used in the azimuth independent mode to analyze satellite radiances for nadir viewing geometry. Work is currently underway to generalize the model for azimuth dependent cases.

Extensive statistical intercomparisons between the radiative transfer model radiances and satellite image radiances (NOAA-7) have been done for January 1984, confirming a close agreement between model and image radiances for VIS, near-IR and IR channels as well as for the 3.7 micron channel, which had not

been validated previously. Discrepancies between model and data were found to be within the limits of accuracy of data. Systematical errors or other biases were below limits of detection.

The sensitivity study for AVHRR radiative model has been continued to study the influence of the experimental uncertainty of self-broadened continuum water coefficients. It was shown that neglecting water vapor line absorption for the IR channels can cause an error up to 2K in the tropical areas.

We also completed a thorough investigation of the effects of particale size and phase functions, as well as the geometrical thickness of the clouds for the five AVHRR channels.

The radiative transfer model for VIS, IR and water vapor METEOSAT channels has also been validated to within limits of accuracy of data. The sensitivity experiments and information content analysis for clear and cloudy conditions has been completed. A study of the possibility of using the water vapor channel as a source of additional information for retrieving cloud cover information has been started.

PRELIMINARY SATELLITE OBSERVATIONS OF SAHARAN DUST STORMS

Dust storms play an important role in both atmospheric and geological processes. Atmospheric dust can affect the radiation budget and cloud formation. Eolian dust constitutes a significant proportion of deep-sea sediments. Variations in the fraction of sand in marine sediments have been used to infer paleo-aridity and wind circulation patterns (Rea et al., 1985). Since major dust storms on Mars develop under similar conditions as on earth, study of Saharan dust outbreaks provides a useful analog for martian eolian processes.

Meteorological satellites have proven advantageous in following dust outbreaks and deriving Saharen aerosol optical thicknessess over the Atlantic Ocean. In this study, Meteosat data were used to identify and track the spatial

and temporal evolution of three Saharan dust events. The source areas of dust plumes have been located and related to surface and meteorolgical conditions, conducive to dust mobilization and transport. The magnitude of the thermal depression associated with Saharan dust clouds has been determined, for summer noon, as one means of differentiating dust from water clouds on thin cirrus, in a preliminary step toward automated dust cloud recognition, using a modified ISCCP cloud algorithm (see Rossow et al., 1985).

The Meteosat data used in this study come from the beginning of the ISCCP archive (July, 1983). The satellite data have been spatially resampled to an E-W spacing of ~27 km at nadir. The temporal coverage is repeated at 3 hr. intervals. Visual interpretation of daytime imagery on the GISS Hacienda 7350 image processor allowed selection of three discrete dust events in Northwest Africa for further study. These include 1) an outbreak traversing the Algerian coastline (July 26-28), 2) a spiral dust cloud over south-central Algeria (July 28-29) and 3) a smaller dust cloud drifting over southern Algeria into Mali and Mauritania (July 1-3).

Meteorological and ground observations

Synoptic meteorological conditions were determinmed from Northern Hemisphere surface charts from the National Climate Data Center (NOAA NESOIS NCDC), at 6 hr. intervals, supplemented by ground meteorologic data from the NOAA NMC global station network, for daytime observations (12, 15, 18 GMT). Clear day surface reflectances along selected scan lines were compared with topographic, geologic and soil maps.

Synoptic features, characteristic of summer include highs centered over the Azores and Mediterranean, and a low at ~20°N, in the Sahara, north of the ITCZ. Strong S-SE desert winds, along the NE edge of the Saharan low, triggered off dust storms on July 26 and 27, marked by low ground visibilities (<1 km). The

dust plume, tracked in the thermal channel (10.3-12.9 μm) over land and in the visible-near IR (0.4-1.1 μm) over water, spread north toward Spain on July 26, but shifted NNE toward the Balearic Is., the next day. The dust source was tentatively located at ~34°N, 0-0.03°, in deflatable Plio-Pleistocene alluvium.

On July 28, dust mixed with water clouds, had organized into a broad, curved band, extending from N. Mali into central Algeria, within the Saharan low. The cloud continued to expand counterclockwise, until, by noon, July 29, it had formed an almost closed loop. The 6 μm band, although noisy, shows low moisture content--hence predominantly dust.

A localized dust outbreak developed in S. Algeria, July 1, along the sharp topographic gradient marking the western flank of the Ahaggar Mts. Dust could have been derived from alluvium in the numerous NE-SW trending wadis. The dust cloud was identified as such, by its smooth, thermal depression and confirmed by low ground visibility (1 km) and strong ESE winds (19 knots), at Tessa lit (noon, July 2), at the same geographic position and time.

East-west traverses, each 100 pixels across and extending from the Atlantic coast across the Sahara, were observed over a period of 3-5 days, at noon GMT, in both visible and thermal channels. Variations in surface reflectances on clear (cloud-free) days, were associated with topographic and geologic features. In general darker features correlated with higher elevations (greater vegetation-cover, and/or rock outcrops), while brighter terrain corresponds to lower elevations, loose Plio-Pleistocene sediments and active sand dunes--prime source regions for airborne dust.

Dust Cloud Measurements

Average differences in brightness temperatures were obtained for corresponding pairs of pixels, respectively covered by a dust cloud, and over the

same surface, on a different, cloud-free day. Average temperature differences between the same pairs of pixels were also measured on two clear days.

Dust clouds are differentiated from water clouds over land by smoother and less variable reductions in brightness temperature, yet warmer than ordinary water clouds (7300 K); little to no change in reflectance is observed in the visible band.

For all three dust events, the average noontime brightness temperature of a dust cloud is consistently 9-10 K ± 5-7 K cooler than that of the underlying surface on a clear day. However, the average temperature differences between two clear days are invariably less than 4 K, for the same area. Average temperature differences between water clouds and clear ground, on the other hand, are around 22-25 K ± 17-18. The high variability may indicate a partially broken cloud cover, with greater thermal contrast between clouds and exposed surface. While the actual temperature of either dust on water cloud depends on latitude (the further south, the warmer), the termal differences between water-dust cloud, or dust cloud-surface are each around 10-12 K, at all three localities studied. This suggests use of a sliding temperature difference threshold as a means of differentiating water from dust clouds.

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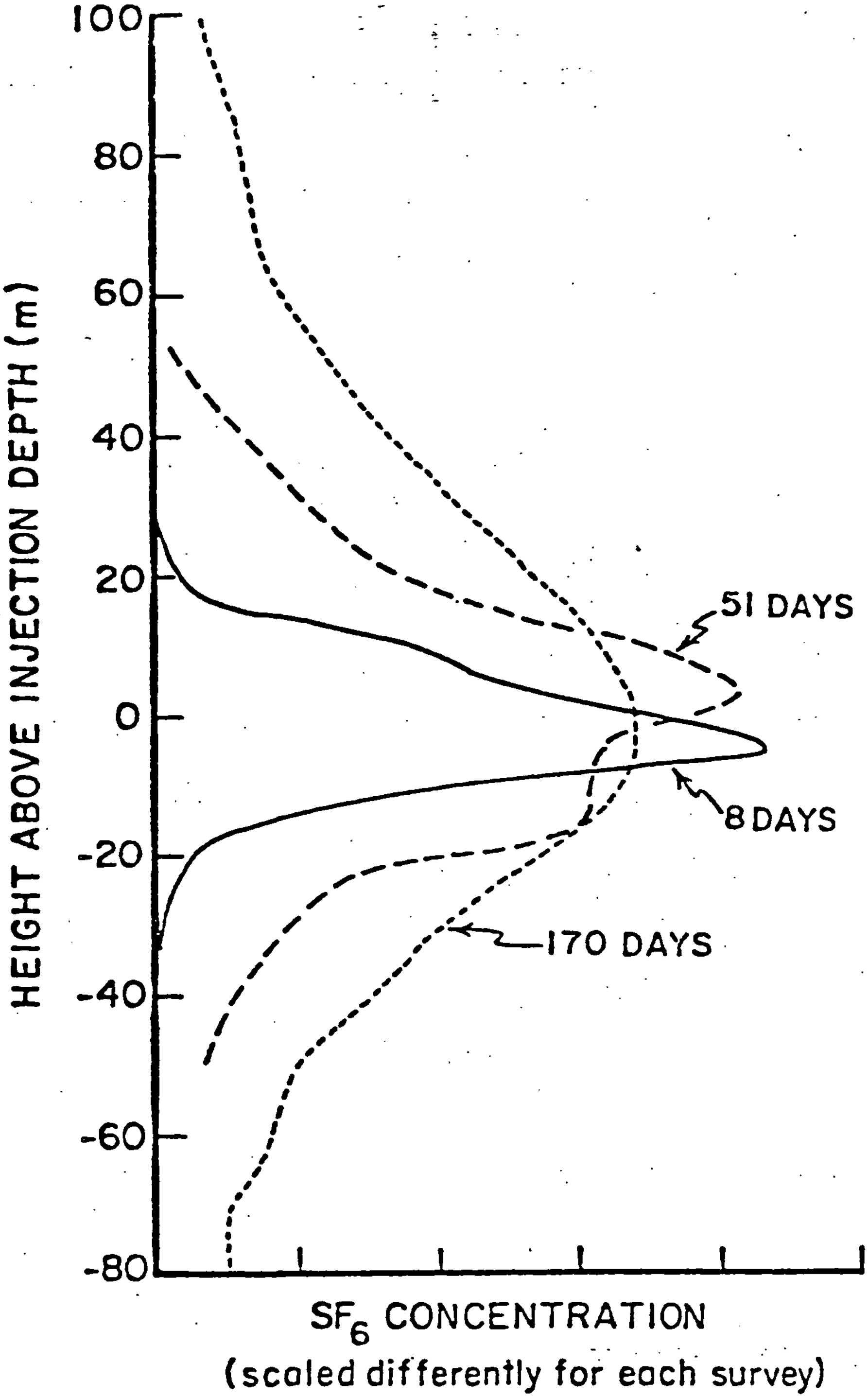
TASK C

AIR-SEA GAS EXCHANGE

The work accomplished from this study came from the demonstration of the great power of purposeful tracers in studying gas exchange between the ocean and atmosphere and mixing processes within the sea. This work was started under a small grant provided by the DOE-CO_2 program which permitted John Shepherd of Lowestoft, England to spend a year at Lamont-Doherty doing a feasibility study regarding purposeful tracer experiments. Jim Ledwell, Rik Wannikhof and I have been able to obtain the wind velocity dependence of gas exchange rate for three lakes, using SF_6 as a tracer. This is a first in natural systems. We hope to do similar experiments in the open ocean. Working with Andy Watson of Plymouth, England, we have also demonstrated the power of SF_6 as a tracer of internal ocean mixing processes. We have measured the lateral dispersion rate along isopycnals, the vertical mixing rate across isopycnals and placed limits on the rate of vertical advection in an isolated deep basin in the California borderland (see attached Figure).

VENTILATION OF THE OCEANIC THERMOCLINE AND OF THE DEEP SEA

Our studies involved an appreciation of the role of the ocean in climate change. As you know, we are convinced that in the past, climate change has involved sudden reorganizations of the joint mode of operation of the ocean-atmosphere system. These changes appear to have caused large changes in the climate for high latitude regions (especially western Europe) and in the atmosphere's CO_2 content. We suspect that they may be important in the future, as well. *Our breakthrough in this area, is the demonstration that radiocarbon* measurements made with accelerators on handpicked benthic and planktonic foraminifera, can be used to reconstruct the rate of deep ocean ventilation



Vertical distribution of tracer in Santa Monica Basin for 3 surveys. Heights are given relative to the injection surface. Concentration scales are different for each survey to make the peak heights appear roughly the same. The mean profiles 8 days, 51 days and 170 days after injection are shown. The broadening of the profiles with time gives a vertical eddy diffusivity of about 0.4 cm^2/s. A background correction has been made for the 170 day profile, but is uncertain, so the tails of this profile are as yet difficult to interpret.

during glacial time. Armed with Boyle's new cadmium method, our new $^{14}C/^{12}C$ method and the existing $^{18}O/^{16}O$ and $^{13}C/^{12}C$ methods, scientists will be able to learn much more about the changes in ocean operation which marked the transition from glacial to interglacial time. In so doing, we will be able to initiate thinking about the role of the ocean's thermohaline circulation in the coming greenhouse warming.

VERIFICATION OF THE HYDROLOGIC CYCLE IN THE ATMOSPHERIC GCM

The work accomplished from this study is derived from the design of a means to test the water cycles in atmospheric general circulation models. Jean Jouzel (of Saclay, France), Jim White (of Lamont-Doherty), Randy Koster (of M.I.T.) and I, have worked with scientists at GISS to program their GCM for the isotopes of water (HDO, HTO, and $H_2{}^{18}O$). We have compared the pathways followed by bomb testing tritium from stratosphere to ocean in the model with those which appear to have been followed in the real world. We have come upon a very large discrepancy. In the real world, the ratio of vapor impact delivery to precipitation delivery of tritium to the sea surface appears to have been about 2.6. In the model, this ratio is 0.7 and is robust. We are currently trying to find out the source of this disagreement. In finding it, we will learn important things about the Earth's water cycle and its representation in models.